



## **Innovationskonsortiet Mikrometal**

Cold forging of industrial micro components

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*Published in:*

Metallurgi, Design og Innovation

*Publication date:*

2007

*Document Version*

Publisher's PDF, also known as Version of record

[Link back to DTU Orbit](#)

*Citation (APA):*

Arentoft, M., Paldan, N. A., Eriksen, R. S., & Hansen, H. N. (2007). Innovationskonsortiet Mikrometal: Cold forging of industrial micro components. In *Metallurgi, Design og Innovation: Vintermøde 2007* (Vol. Dansk Metallurgisk Selskab)

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# INNOVATIONSKONSORTIET MIKROMETAL

## Center for Metalliske Mikroprodukter

**Cold forging of industrial micro components**

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**ABSTRACT:** *Cold forging of micro metal parts is a process which gives high productivity, high strength and high precision components. To establish a production line for mass production of such components, a number of techniques and methods need to be developed. A concept for a flexible tool system for research in cold forging of micro-components has been developed. It is designed for the eight basic cold forging processes with some replaceable process dependent parts and further developed for multi step processes. The precision of the tool system is crucial owing to the narrow tolerances on the dimensions of micro-components. This requires the manufacture of die cavities with an internal diameter in the sub millimeter range, having complex internal geometry with tolerances in the range of microns. Micro edm and electroforming are both processes which fulfill such requirements. A method for producing cylindrical billets by cropping is analyzed. The tool design is tested by cold forging of an industrial component for a miniature electronic device. The ejection of the component may lead to collapse of the thin sections due to high surface to volume ratio. Considerations presented in this work are a step towards the goal of establishing a mass production line for manufacturing of micro metal components.*

Key words: micro forming, tool manufacturing, cold forging, tool concept

### **Introduction:**

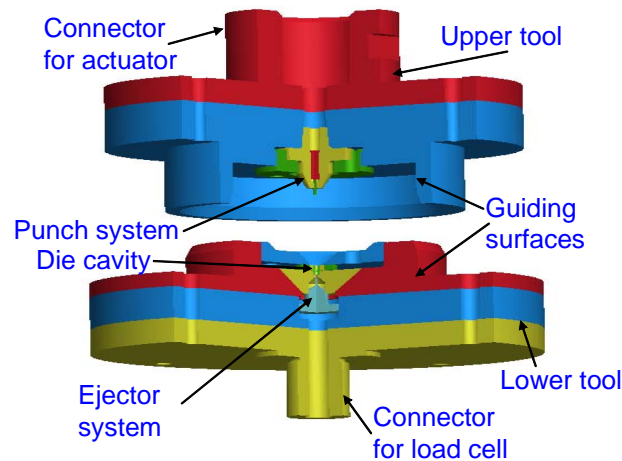
The growing market of modern products like mobile phones, personal digital assistants (PDAs), mp3-players etc. has led to an increased demand for small and accurate metallic parts. So far these parts have mainly been manufactured by traditional machining processes or chemical etching, both of which are expensive and wasteful production methods. This calls for the development of a production system that can meet the demands for high productivity, high reliability, low cost and environmental acceptable. Bulk metal forming in macro scale meets these demands to a great extent, but the technology cannot directly be transferred to the micro scale, [1-2].

### **Flexible tool system:**

To establish a cold forging line for mass production of micro metal components, a tool system is needed. To compete with existing processes like machining and etching, the productivity becomes an important factor. The system is therefore planned to run up to 300 strokes a minute. With this speed, a standard production batch at 100.000 pieces can easily be produced in an 8 hour day, meaning that the flexibility of the tool system becomes a key issue. The flexible cold forging tool is designed for the 8 basic cold forging processes [3]. The design phase covers optimisation of all following main tool elements:

- Precision guiding system between upper and lower tool part ( $<10\text{ }\mu\text{m}$ )
- Ejector system for specimens down to 0.3 mm
- Flexible die insert with high precision positioning
- Flexible punch system
- Possibility for prestressing of the die insert for high pressure processes.
- High precision connections to press or actuator.

A tool system is mounted in a small test press driven by a computer controlled linear servo actuator with a  $1\text{ }\mu\text{m}$  resolution encoder [4]. The actuator features a high number of windings, allowing accuracies better than  $10\text{ }\mu\text{m}$  to be achieved. The tool system is depicted in Figure 1.

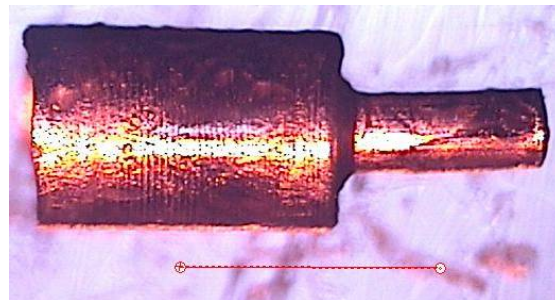


*Figure 1 Flexible tool system for micro forging*

The tool concept is tested by forging of a silver contact pin which included a forward rod extrusion from 0.8 mm down to 0.3 mm (reduction at 86%), shown in figure 2. From these tests, valuable experience is obtained, which is taken into account in the future design of the flexible cold forging tool.

The required force for ejection often caused the extruded part of the component or the ejector pin to collapse. This is due to the high surface to volume ratio of thin micro components.

During the tests, it is realised, that the alignment precision of upper and lower tool is unacceptable. Only by optimising the position of each tool part relative to the other, a successful process can be obtained. Such individual positioning is not suitable for mass production equipment, and the concept therefore needs to be modified.



*Figure 2 Cold forged contact pin by forward rod extrusion*

### **Production line for production of micro metal components**

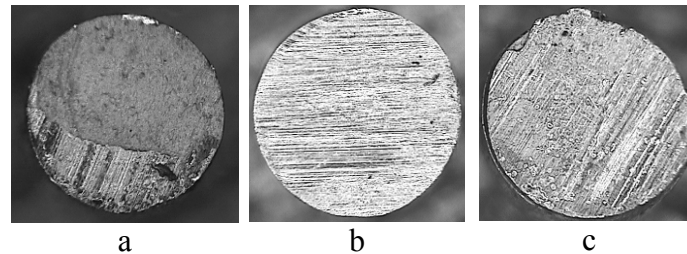
The concept of the flexible cold forging tool will be the principal component of a new production line for mass production of micro metal parts. However, in order to establish such production line, a number of supporting techniques and methods need to be developed. This includes a billet preparation module, a lubrication technique, a transfer system with corresponding grippers, manufacturing methods for micro tools, a process control unit and a number of load and position sensors.

The billets for forging the silver pin are made by conventional machining, which is costly and non-efficient and comparable to the process of producing the final component by machining. A high effective, high precision method is therefore required for manufacturing small cylindrical billets. For this purpose, the cropping process has been investigated. By applying hydrostatic pressure or using high speed cropping a well defined cropping zone can be obtained. To test these approaches, a testing rig is developed. A Ø1.9 mm aluminium rod is axial loaded with more than 2 times the flow stress or cropped at app. 12 m/sec. in lengths of 2.11 mm. The device for cropping with hydrostatic pressure is shown in Figure 3.



*Figure 3 Device for cropping at hydrostatic pressure*

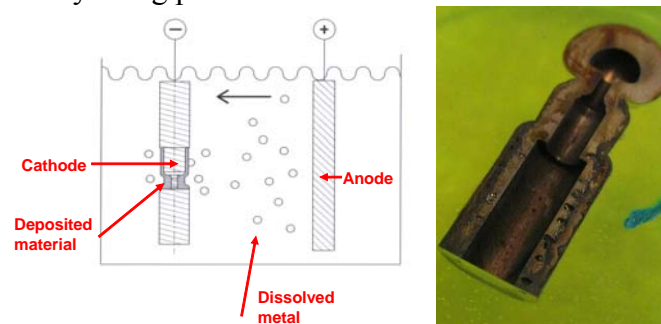
In figure 4, the result of the 3 methods is shown. The best result is achieved by cropping under hydrostatic pressures, giving raise to low volume variance, which is the key quality parameter of the cropping process. Also, the roundness of the billet is well preserved when cropping under hydrostatic pressure. The cropped volume is in all 3 cases within 1% of the specified volume, which is acceptable for most processes. By cold forging of cropped- and machined billets, no measurable difference is found.



*Figure 4 The cropped surface obtained by conventional cropping (a), cropping with hydrostatic pressure (b) and high speed cropping (c)*

The tools for forging of the silver pin was made by edm die-sinking in Vanadis 10 hardened to 64 HRC by a collaborator. This process turned out to be very time consuming and costly. As an alternative, the dies could be made by electroforming or micro edm-milling at IPU. These methods are tested by manufacturing the tools for a two step cold forging process of a component for miniature electronics.

In the electroforming process, a cathode of aluminium is machined to an outer geometry similar to the inner geometry of the die. A hard nickel alloy is deposited on the aluminium. Subsequently, the aluminium can be etched away, and a die with the requested inner geometry is left. The method has been tested with 3 different nickel alloys. In figure 5, the method and a cross section of an electroformed die is shown. At present, a die with a hardness of 440 HV<sub>25g</sub> has been tested by forging a lead billet. A die with a hardness of more than 800 HV<sub>25g</sub> is currently being produced.



*Figure 5 The principle behind electrofoming of die for cold forging (left) and a cross section of an electroformed die, before machining of the outer geometry (right).*

As an alternative, the dies can be made by micro-edm. The chosen tool material is a slice of a 8 mm ISO 8020 form B cutting punch made of Vanadis 23 hardened to HRC62-64. By micro-edm with a 0.3 mm electrode, the die can be machined in a day.

The main quality properties of the die are geometry, roughness and strength. A replicating method using a commercial silicone is used for measuring the inner geometry, since conventional measuring techniques cannot be used in so deep and narrow holes. In figure 6, sections of the two replicas are shown. It is seen, that the edges are sharper on the electroformed die than for the one made by micro-edm.

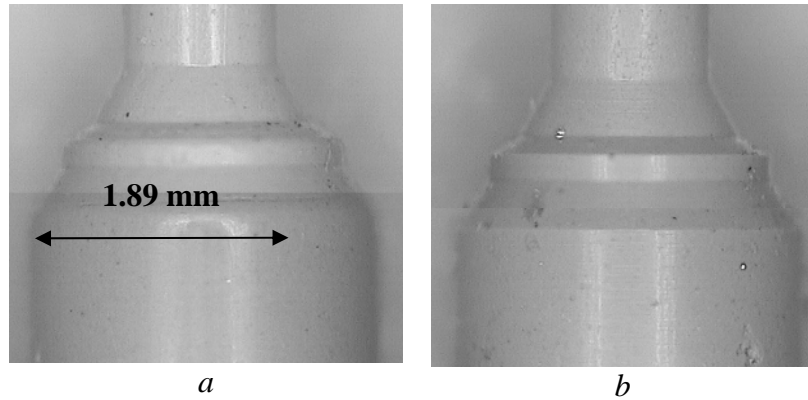


Figure 6 a: Replica of die made by micro-edm. b: Replica of die made by electroforming.

Due to the low hardness of electroformed dies, the edm-machined tool is chosen for the real cold forging process. The punches and ejector pins are made by micro-edm and grinding of HSS drills, which are inexpensive and available in almost any diameter. The punch is mounted in a flexible punch holder by backward extrusion of an aluminium billet, which also ensures alignment of the upper and lower punch. In figure 7, the 2 step forming process, mounting of punch in punch holder and tools parts for step 1 are shown.

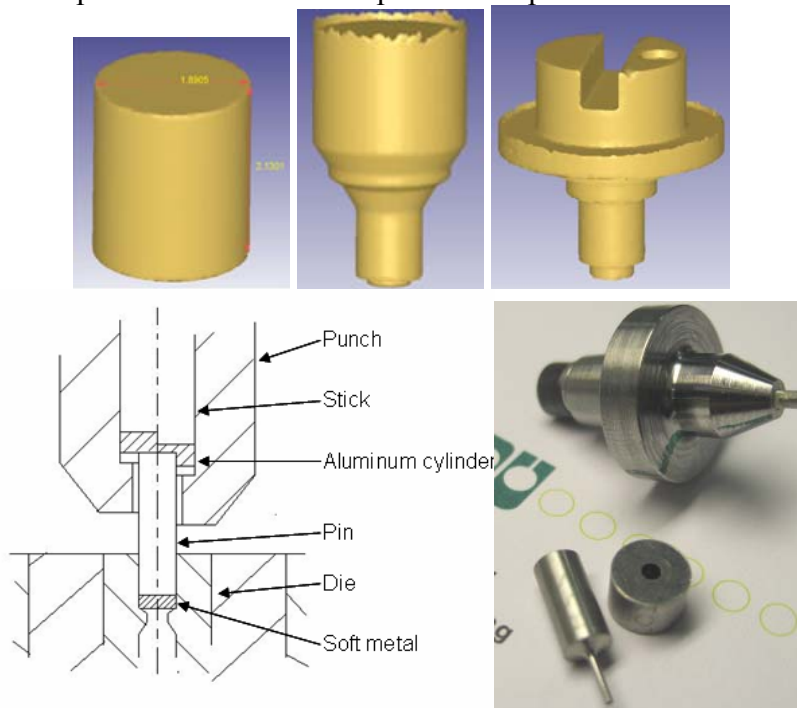


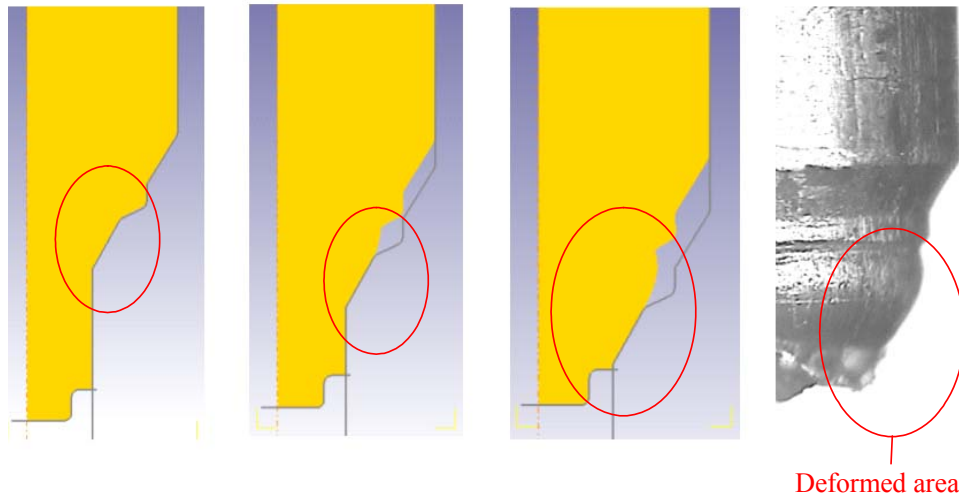
Figure 7 Top: The 2 step process, Bottom left: Alignment and assembly of punch and punch holder Bottom right: The tool parts for step 1.

The tool parts and flexible cold forging die are assembled and mounted in the mini-press. The process is tested by forging of cartridge brass and AA6060. The load for forging the cartridge



brass exceeds the capacity of the mini-press at 5500 N. When forging aluminium, the first attempt resulted in a component with some backward extrusion into the 40  $\mu\text{m}$  gap between punch and die. This problem is solved by manufacturing a new punch just a few microns smaller than the inner diameter of the die.

Another problem arose in front of the component, where the material is supposed to flow into an  $\varnothing 0.5$  mm cavity in the ejector. This cavity is under-filled due to entrapped lubricant. By running the process almost dry, a sound component is achieved. However, during ejection of the component, the extruded part collapses as seen in figure 8.



*Figure 8 The formed component collapse during ejection. Simulation sequence left and collapse component to the right*

This is probably due to the very limited lubrication. The problem is solved by several actions like annealing the aluminium; lubricate the billet with a thin coating of  $\text{MoS}_2$  and only loading the punch with the needed force. The extruded part will then be deformation hardened and thereby harder than the upper part, pick up can be avoided and the elastic stresses in the die will be limited.

Giving the experience from step 1 as starting point, a successful tool design for step 2 is achieved in first attempt. In figure 9, step 1, step 2 and the reference machined component are shown.



*Figure 9 Cold forged micro part (top and left) and the machined component (bottom right).*

The production system will be designed for multi-step processes, therefore a transfer system is needed. The system will transport the billet from the billet preparation station through the forming stages and leave the formed component on a slot-conveyor. To test different transfer and gripper concepts, a special designed testing rig is developed. Based on experience from this, the transfer system for the production line is designed and currently being manufactured. It consists of a high precision bore, where the specimens are kept in position by van der Waal

forces and the injection/ejection is linked to the main stroke of the press. A linear actuator transfers the component to the next forming station with a precision of 3 microns. [6], [7].

### **Conclusion:**

The industry requires high volume, high precision micro metal components. For this purpose, cold forging is a suitable process. The requested productivity causes demands of a flexible production line. A concept for a flexible cold forging tool is developed and tested. The supporting methods are analysed and solutions are proposed. The billets can be prepared by cropping, where the smooth surfaces are obtained by applying a hydrostatic pressure. The tools are produced by micro edm or electroforming. The best surface quality and sharpest edges are found by electroforming, but the edm manufactured tools is preferred due to higher strength and shorter production time. An industrial micro component for a miniature electronic device is cold forged in two steps. Some problems related to flash, lubrication, under-filling and ejection are resolved and valuable experience is gained for future design of micro cold forging processes. Having such process, the basis for a production line for mass manufacturing of micro metal parts using the cold forging technology is established.

### **Acknowledgement:**

The authors wish to thank the European Commission and the Danish Ministry for Science Technology and Innovation for supporting the work by the EU project MASMICRO, no. 500095-2 and the Innovation Consortium MIKROMETAL, no. 66334. Furthermore Dr. P.T.Tang, M.Sc. I. Tanaka and M.Sc. Students J.M. Pedersen, C. Hansson, J. Duus and J. Holstein are appreciated for their contribution.

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